AD-A042 110   STANFORD UNIV CALIF DEPT OF MATERIALS SCIENCE AND EN--ETC   F/G 20/12
AN INVESTIGATION OF DEEP IMPURITY LEVELS IN GAAS BY PHOTOCAPACI--ETC(U)
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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) ARO-11744.2-EL

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER ARO-11744.2-EL	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) AN INVESTIGATION OF DEEP IMPURITY LEVELS IN GaAs BY PHOTOCAPACITANCE AND RELATED TECHNIQUES.		5. TYPE OF REPORT & PERIOD COVERED Final Report, 1 Jul 74 - 30 Jun 77
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Richard H. Bube		8. CONTRACT OR GRANT NUMBER(s) DAAG29-74-C-0025, DAHC04-74-C-0025
9. PERFORMING ORGANIZATION NAME AND ADDRESS Stanford University, Stanford, California 94305		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS U. S. Army Research Office, Post Office Box 12211, Research Triangle Park, NC 27709		12. REPORT DATE July 1977
		13. NUMBER OF PAGES 9
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

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17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Impurities	Electrical properties
Gallium arsenides	Copper
Epitaxial growth	Chromium
Liquid phases	Oxygen

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The purpose of this research program was to investigate the behavior and identity of impurities in high quality liquid phase epitaxial GaAs. Photocapacitance measurements were combined with photoluminescence and other well established techniques to provide a complete electrical characterization of the material. In order to identify possible impurities, similar characterizations were carried out on epitaxial GaAs with Cu impurity added either during layer gorwth or by diffusion after growth, and on bulk cyrstals of GaAs doped with chromium and oxygen.

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FINAL REPORT

AN INVESTIGATION OF DEEP IMPURITY LEVELS IN GaAs BY PHOTOCAPACITANCE AND RELATED TECHNIQUES

Contract DAHC04 74 C 0025

U.S. Army Research Office
Research Triangle Park
North Carolina 27709

July 1, 1974 - June 30, 1977

Submitted by

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July 1977

PURPOSE

The purpose of this research program was to investigate the behavior and identity of impurities in high quality liquid phase epitaxial GaAs. Photocapacitance measurements were combined with photoluminescence and other well established techniques to provide a complete electrical characterization of the material. In order to identify possible impurities, similar characterizations were carried out on epitaxial GaAs with Cu impurity added either during layer growth or by diffusion after growth, and on bulk crystals of GaAs doped with chromium and oxygen.

MAJOR RESULTS

Undoped High Purity LPE GaAs Layers

Undoped high purity LPE GaAs layers on semi-insulating and p^+ substrates have been grown in a graphite-quartz-hydrogen system. The layers were either n-type below or p-type above a critical melt-growth system bakeout temperature. The n- to p-conversion appears to be related to changes in the carbon, silicon, and oxygen concentrations in the melt that arise from thermochemical reactions in the growth system. Photocapacitance and transient capacitance measurements showed that both n- and p-type layers are compensated by several deep acceptors. Photocapacitance and hole trapping transient techniques showed that n-type layers near the transition contain two dominant hole traps at $(E_v + 0.42)$ eV and $(E_v + 0.67)$ eV. Photocapacitance and transient capacitance measurements on p-type layers revealed the presence of 3 hole traps at $(E_v + 0.42)$ eV, $(E_v + 0.67)$ eV, and $(E_v + 0.81)$ eV with densities an order of magnitude higher than those in the n-type layer. Thus the n- to p-transition is also related to the formation and incorporation of several deep acceptor-like traps. When the n-type layer is annealed, the concentration of the $(E_v + 0.67)$ eV traps appears to increase at the surface, suggesting a relationship with arsenic vacancies. Therefore impurity complexes with native defects appear to influence the n- to p-conversion.

In addition, near the interface between the n-type layer and the p^+ substrate, deep levels at $(E_v + 0.44)$ eV, $(E_v + 0.75)$ eV, and $(E_v + 1.12)$ eV were observed. These levels may arise from the outdiffusion of contaminants from the substrate, partially confirmed by their concentration profile observed.

LPE GaAs Layers with Cu Present in Melt During Growth

Cu introduced into the growth of n-type LPE GaAs increases the electron density. This increase of electron density is qualitatively consistent with photoluminescence results which suggest that the incorporation of Cu causes the disappearance of luminescence bands involving Si_{As} and C_{As} (acceptor-type species). Emission spectroscopy was used to determine that the distribution coefficient is approximately 10^{-4} for Cu in LPE GaAs. Photocapacitance effects for Schottky barriers formed on these layers indicate four levels at $(E_v + 0.20)$ eV, $(E_v + 0.45)$ eV, $(E_v + 0.65)$ eV, and $(E_v + 0.70)$ eV. The level at $(E_v + 0.45)$ eV is associated with Cu_{Ga} as described in more detail for the samples with diffused Cu below. The same level was observed in the layers grown with Cu impurity in the melt by measurements of capacitance transient as a function of temperature.

LPE GaAs Layers with Diffused Cu

When Cu diffuses into a grown layer, it behaves as a conventional acceptor. It is possible to increase the resistivity to values greater than 10^3 ohm-cm, thus making various photoelectronic measurements possible. Thermal and optical quenching of photoconductivity indicate that the Cu-related defect responsible for the sensitization of n-type photoconductivity is a center with a ratio of capture cross section for holes to that of electrons of 10^5 to 10^6, an electron capture cross section of about 10^{-21} cm^2 at 90^oK, and an energy level about 0.43 eV above the valence band. Three electron and two hole traps were also observed through measurements of thermally stimulated conductivity on these layers. The electron traps have depths of 0.19, 0.24, and 0.30 eV, and electron capture cross sections of about 10^{-18} cm^2. The hole traps have depths of 0.38 and 0.60 eV, and hole capture cross sections of about 10^{-16} cm^2. Estimated trap densities for all the traps is about 10^{16} cm^{-3}.

Bulk-Grown GaAs:O

Two distinct peaks were observed in photoluminescence at 0.65 and 0.37 eV. Photocapacitance measurements indicate the presence of three principal levels located at $(E_c - 0.795)$ eV, $(E_c - 0.46)$ eV, and $(E_v + 0.39)$ eV. The first appears to be the deep oxygen donor level and shows a good correspondence with the Lucovsky model for variation of optical cross section with photon energy. The level at $(E_v + 0.39)$ eV appears to be related to the 0.37 eV peak observed in photoluminescence and associated with Fe impurity. It has a large cross section for holes and the optical hole cross section has been determined by interactive quenching experiments. The the identity of the $(E_c - 0.46)$ eV level is unknown but is probably related to native defects.

Bulk-Grown GaAs:Cr

The GaAs:Cr material shows a very sharp peak in the photocapacitance and optical absorption centered around 0.9 eV. The sharp drop off at photon energies greater than 0.9 eV was experimentally verified to be due to simultaneous optical filling transitions from the valence band by measuring the optical electron and hole cross sections for the Cr level separately. Two other levels located at $(E_c - 0.7)$ eV and $(E_v + 0.43)$ eV are also detected in the same material. The Cr level does not give a good fit to the Lucovsky model and this appears to be related to a lattice relaxation occurring during the optical transition.

Crystal Growth Effects

LPE GaAs of different crystallographic orientation exhibits different distribution coefficients. Films grown by the LPE technique on (111)B and (100) semi-insulating GaAs:Cr substrates show a greater net donor concentration for the (111)B orientation than for the (100) orientation. A theoretical description has been found by considering the effect of an interface electric field produced by differential vacancy formation on the Ga and As interface sites. This interfacial electric field influences both the equilibrium solute distribution coefficient and the net interface distribution coefficient when diffusion communication across the solid interface layer becomes limiting. Under conditions of positive interface electrostatic potential, this theoretical model also predicts that the incorporation of acceptor impurities is favored over donor impurities.

REPORTS AND PUBLICATIONS

Semi-Annual Progress Reports

July 1 - September 30, 1974

October 1, 1974 - March 31, 1975

April 1, 1975 - September 30, 1975

October 1, 1975 - June 30, 1976 *

July 1, 1976 - December 31, 1976

* This report was a special 58-page detailed report of work to date.

Publications

P.K.Vasudev, B.L.Mattes, E.Pietras and R.H.Bube, "Excess Capacitance and Non-Ideal Schottky Barriers on GaAs," Solid-State Electronics 19, 559 (1976)

P.K.Vasudev, B.L.Mattes and R.H.Bube, "Deep Levels in High-Purity LPE GaAs by Photocapacitance and Related Techniques," IEEE GaAs Conference, September 1976

S.S.Chiao, B.L.Mattes and R.H.Bube, "Photoelectronic Properties of LPE GaAs:Cu," submitted for publication to Journal of Applied Physics

P.K.Vasudev and R.H.Bube, "Deep Levels in GaAs:O and GaAs:Cr Crystals by Photocapacitance and Related Techniques," to be submitted to Journal of Applied Physics

SCIENTIFIC PERSONNEL

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